# Building Design, Complexity and Manageability

**Adrian Leaman [1] and Bill Bordass [2]**

**[1] Managing Director, Building Use Studies Ltd. [2] Principal, William Bordass Associates**

Revised July 1994. First published in *Facilities,* September, 1993.

## Introduction

This paper looks at complexity in office buildings and the consequences, desirable and undesirable. It draws on evidence from studies of comfort, control, productivity, health, energy efficiency and human satisfaction carried out in offices in the United Kingdom since 1985. From this work, we know that many office buildings do not function as well as their designers originally intended. They are frequently uncomfortable for their occupants, especially in summer, and sometimes make people chronically ill. This results in lower human productivity, a substantial hidden cost to many organisations. Their energy consumption is often excessive, and consequently the related emissions of carbon dioxide, one of the causes of global warming.

## Sources of complexity

Occupants utilise spaces, equipment and technology to help them perform work tasks. People usually strive to give their personal environment as much variety as they think is required to carry out their range of tasks comfortably and successfully - not too hot, not too cold, not too much space and not too little. If the necessary requirements cannot be met, people often become uncomfortable or dissatisfied. Tolerance of conditions ranges differ from time to time, from one person to the next, between groups of people working together, and with status, roles, tasks, goals and working situations.

Surveys are revealing that the best work spaces are often those where variety is not excessive, and where systems are as simple as possible for people to manage and change. Two basic dimensions - one concerned with physical properties of space and the environment, and the other with management processes over time - fundamentally affect the performance and satisfaction of office occupants.

These two "dimensions" are also sources of complexity. The first comes from the increasing tendency of activities to conflict with each other when the number of activities, or their density, is increased. The second type of complexity is related to the first. Human and physical systems are prone to breakdown or failure, which creates uncertainty for their users. As the chance of functional conflicts increases, so does the risk of failure, and this can make occupants increasingly unsure whether systems are actually working or not, which reduces their tolerance of them.

Underpinning the chances of functional conflicts and likelihoods that things may not work properly, are the different "levels" which operate in buildings, see Figure 1. They range from geographical location at the macro scale down to behaviours of individuals at micro scales. Often, buildings are planned and designed starting with macro decisions and finishing, sometimes by default, with micro. The way that design and construction is organised means that decisions at higher levels often "cascade" constraints down to lower levels, resulting in the arbitrary inheritance of constraints for users and occupants at the "bottom" levels. Buildings which are designed "bottom up", that is, starting with studies of users' needs and occupants' requirements, are often no better because they fail to account realistically for constraints elsewhere in the total system.

For people and organisations to use buildings as effectively as possible within each of the levels, functional conflicts and uncertainty need to be kept as low as realistically possible. To help achieve this, people need simple and clear technical interfaces, effective and unambiguous decision-making hierarchies, and, when they want to make interventions, rapid responses and predictable outcomes.

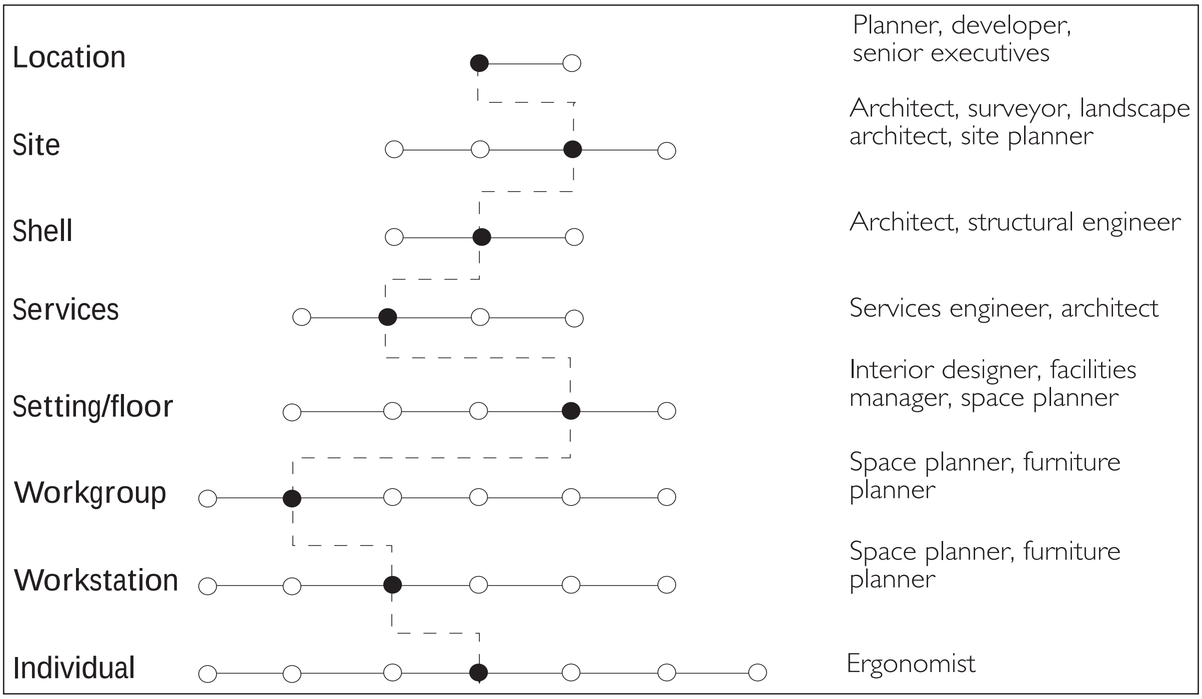



**Figure 1**
**Buildings and levels**
Buildings fit into a logical, hierarchical structure. Each level in the diagram represents a sub-system and carries with it a major decision - geographical location, first, then site, shell and fabric, services system, interior layout, furniture system and so on down to facilities for individuals at their work areas. A hypothetical decision path between alternatives is shown to illustrate the decision logic.

The characteristics of each level set constraints for the next level down - geographical location for site, site for shell and fabric, fabric for services system and so on. Ill-advised decisions at the top tend to be much harder to reverse than those at the bottom. Constraints introduced higher up cascade down.

There are also constraints in operation in the controls and communications structures which involve decisions and information moving between levels. Many buildings have weakly-developed control and communication interfaces between levels because of the tendency to divide sub-system levels into specialist bodies of knowledge, as shown.

This stratification simplifies design process logistics, but it also introduces additional constraints which increases the likelihood of functional breakdowns between levels. For example, there is evidence that lack of integration between fabric design and services design, especially through lack of attention to detail in windows, can lead to thermal discomfort and other failures in naturally-ventilated buildings.

Source: Revised version of Figure 2.2 from Adrian LEAMAN and Iain BORDEN, *The Responsible Workplace: User Expectations*, chapter 2 of Reference 11.

In practice, robust, adaptive procedures usually work best. If people cannot immediately get what they want from the management and control systems, they will often take the easiest perceived alternative route to achieve what they want, however technically inappropriate it may be. To get things to work properly requires “strategies” for reducing conflicts and uncertainty. These may be the direct result of design decisions or management action, or, best of all, a combination of the two. Increasingly, suitable strategies must be economical and environmentally appropriate as well.

The two types of complexity - one based on the chances of functional conflicts, the other based on increasing uncertainty of performance - are shown in Figure 2.

Uncertainty, feedback and complexity are key concepts in the literature of systems dynamics, as described here by HA Simon.

“In simple cases uncertainty arising from exogenous events can be handled by estimating the probabilities of these events, as insurance companies do - but usually at a severe cost in terms of computational complexity and information requirements. An alternative or supplementary measure is to use feedback to correct for unexpected or incorrectly predicted events. Even if the anticipation of events is imperfect and the response to them less than accurate, adaptive systems may remain stable in the face of sizable jolts. their feedback controls continually bringing them back on course after each shock displaces them. Although uncertainty does not therefore make intelligent choice impossible, it places a premium on robust adaptive procedures instead of strategies that work well only when finely-tuned to precisely known environments.”

HA Simon [Reference 1]

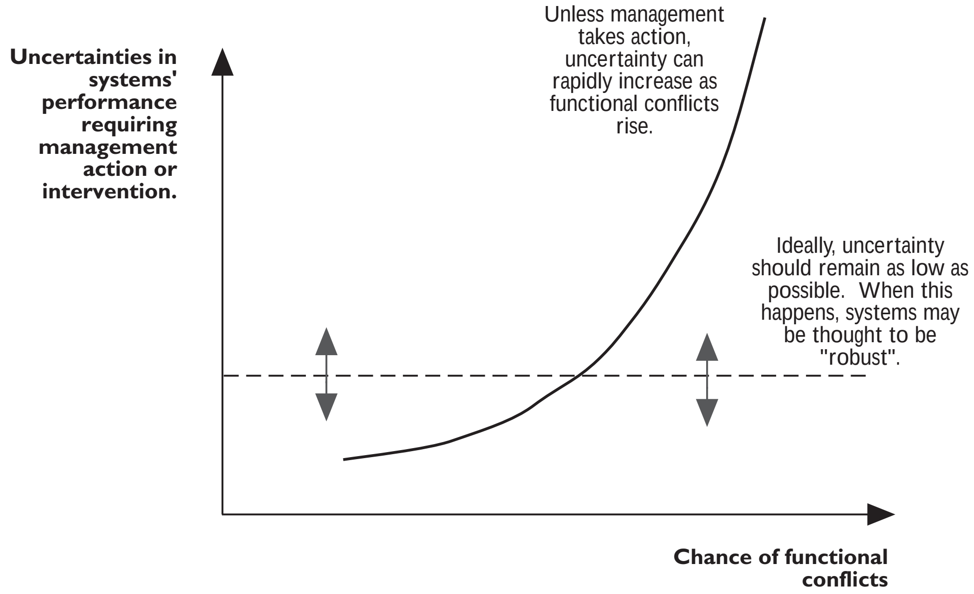



**Figure 2**
**Two types of complexity affecting building performance**

### Resolving the complexity types

Experience shows that to work to best effect, office buildings must:

1) provide an acceptable variety of types of usable space; and

2) help to keep uncertainties for occupants, users and managers as low as possible.

In reality, these requirements usually pull in *opposite* directions. Increased variety in usable space tends to bring with it greater uncertainty and complexity in the user/management dimension. On the other hand, trying to simplify the management requirement can reduce spatial carrying capacities below acceptable thresholds.

A successful strategic approach will aim to resolve these inconsistencies by:

1) examining the likely effects of actual and potential constraints imposed by the spatial properties of the building;

2) ensuring that these spatial constraints create as few obstacles as possible for occupants, users and managers.

Note that these obstacles can be physical (like walls getting in the way) or managerial (the open space takes too much time and effort to plan and keep running smoothly).

### Useful space and uncertainty

The potential that a building possesses for providing useful space comes from its location, the accessibility of the site, the image and physical performance of the fabric/shell, the effectiveness of the services, and the manner in which the building can be sub-divided by floors, work areas and individual workstations. Together, all these factors account for the richness and complexity of useful space. Up to a point, the more potential for variety the building has, the better but the price is usually greater uncertainty in the user and management dimension.

Uncertainty has several “layers” or “levels”, each with its own time horizon. These range from the whole organisation at the top level, through the style and approach of building management, the nature of work tasks, through to individuals’ needs and preferences. For the facilities manager, for example, a furniture system which cannot be easily disassembled and re-configured introduces periodic inefficiencies, which in turn will be passed on to staff who will build up frustration with unsatisfactory arrangements and ultimately require management support to make adjustments (often unsatisfactorily) they would have preferred to make themselves.

At the building level, systems, such as automatic lighting controls, are often abandoned altogether either because the system does not work properly (it may have been poorly designed and/or commissioned badly), or because people cannot understand how the system operates, or because too much time and effort is needed to operate it effectively. At the individual level, inability to freely adjust building controls (like radiator valves, window latches and blinds) and the failure of the associated control systems to produce the desired effects (temperature controls which give no feedback indication whether they have operated, for instance) can create enduring discomfort and frustration.

Wherever the physical and management systems fail to respond properly to demand, waste results, and the consequences are seen in inefficiency, low morale and reduced productivity. Figure 2 shows how these are inter-related. Chances of functional conflicts increase (bottom axis) when more activities take place in a space. For example, in open-plan offices people are more likely to dispute temperature control settings because their individual requirements cannot be easily resolved. This can also lead to much slower response times when settings really do need to be changed, and greater uncertainty about the operation of the total system (vertical axis).

At a certain level of physical complexity, which in offices is around the limit of natural cross-ventilation ( a depth of space from glass to glass of about 12 metres), the uncertainty of response tends to increase much more quickly,. leading to lower user tolerances with the building and its technical systems. Indeed, the additional mechanical services which have to be used for heating, ventilation, cooling and artificial lighting significantly increase the complexity (and thus the uncertainty in use) of the buildings' systems. Unless these additional systems are extremely robust and stable in their operations and functions, and their functions are readily understandable by users, facilities managers and maintenance staff, then uncertainties arising from their operations (which may often be small-scale and seemingly trivial) can easily accumulate and create the possibility of large-scale failures.

All parties involved in the design and running of a building, including designers and managers, usually try to keep uncertainty as low as possible, but they are constrained in different ways. Designers manipulate space and its physical and technical systems, hopefully creating useful space in so doing. Ideally, but often unrealistically, designers hope (and sometimes claim) to create much more useful space. Generally speaking, building occupants try to reduce operational uncertainties at every opportunity, often taking shortcuts to do so. Their behaviour is often not as the building designer anticipated, owing to circumstantial and context-dependent factors which the designer could not be expected to have predicted. Users often take the easiest course of action rather than the most rational - switching on and off lights to try and control glare, rather than using the window blinds, for instance. For management the major constraints are not primarily the physical properties of the building, but the constraints imposed by the organisation and the people within it, its culture, goals, objectives, budgets, mission and ways of working.

## Buildings in use

Buildings in use must resolve both types of complexity within the resources available for running them. Ideally, the building should provide all the useful space that is needed, with as little uncertainty in operation as possible. It is much easier to achieve this in technically simpler buildings with shallower-depth spaces, than in buildings with deeper plan forms and more elaborate technical services.

To remain properly functional, a building needs to compensate for additional functional complexity by devoting extra resources to ensuring that uncertainty is kept within manageable bounds. However, the extra management and maintenance costs required for a more complex building makes it difficult to achieve this. But, without such support, it is likely that useful space will be reduced or degraded - its functionality constantly being compromised by the extra uncertainty. But uncertainty itself may keep rising as conditions get worse, creating just the circumstances which give rise to so-called sick buildings, which are often the consequence of complexity becoming unmanageable. Strategically, it is best to aim for a building where uncertainty in use is not sensitive to functional complexity: that is, with a curve which is as flat and close to the horizontal as possible, and with a level of management support which can maintain the variety required.

### Simplicity and variety

Variety in useful space is a source of potential for users (because with more varied space more activities become theoretically possible in the building) and usually thought to be an advantage worthwhile having. More complex environments have more potential carrying capacity (just like more complex ecosystems also have higher carrying capacities) - they are more likely to support wider ranges of activities more successfully. But they are usually harder, and, for some organisations impossible, to look after within their available budgets. Less varied spaces, on the other hand, are often less costly to run, but they may have a much lower carrying capacity, and make certain tasks very difficult to achieve in practice.

For some people, "simplifying" a building may mean reducing the chances of functional conflicts in the physical spaces and technical systems. Others may wish to reduce user uncertainty by making the building more responsive to need. The first of these may, for instance, involve knocking down walls and partitions and making spaces deeper and more open; the second improving the responsiveness of control systems.

There is a common misapprehension that open-plan offices simultaneously *increase* carrying capacities and *reduce* uncertainty, but many do exactly the opposite. Reducing uncertainty may mean introducing new walls and partitions, improving the intelligibility of control interfaces, rationalising controls and reduce functional conflicts in order to "discipline" the space further.

### Change

Much of the uncertainty dimension is concerned with how people require, trigger, induce and respond to change. This again works at different levels, each with different frequencies and magnitudes of requirement and effect. Recent research [Reference 3] has suggested that the speed of response with which a building and its management can respond to changes at the different levels is a key factor in improving occupant comfort, health and productivity. For example, to be perceived to work well by the occupants, systems must not only maintain reasonable comfort conditions but must be able to respond rapidly and unambiguously when occupants think that the conditions are unreasonable. When the building or its management fails them in this respect, people become frustrated and uncomfortable.

People usually want the best of both in their buildings - not only simplicity in the management processes but also plenty of options in the use of space, plus the ability to re-configure or change the space quickly.

Achieving this in practice means buildings having:

a) "baseload" capability which suits the organisations' main requirements. This can vary greatly with the organisation and the type of work it is carrying out; and

b) capability to deal with change at all levels in the hierarchy.

Buildings which seem to work best usually have enough variety to provide properly for baseload functional requirements - mainly space for activities and comfort for the occupants - without being extravagant. They also have enough "clarity" in the management and control systems to ensure that activities are not swamped by uncertainty. The management and control processes are also capable of responding to required changes in a positive and direct way.

All the dynamic processes shown in Figure 2 are "internal" to an organisation. To these must be added the further uncertainty of the broader external environment. These include fluctuations in markets for products and services, and the ever-changing socio-environmental context. Wasteful consumption and pollution, for example, is increasingly unacceptable.

### Lack of understanding of decision-making strategies.

Many problems experienced in buildings in recent years can be traced to unresolved strategic conflicts like those described above. Too many constraints are deliberately or inadvertently passed down the building hierarchy (Figure 1) with the tacit assumption that either they will be "solved" at the next level down or that there is a plug-in-and-go technological solution waiting somewhere to overcome any problems that may emerge. The effects too often surface only when people at their workstations start complaining of discomfort, ill-health, or go absent, and these, of course, happen years after irreversible design decisions have been made. Often, the root cause is that the building in operation is too complicated for the management resource which can be reasonably be made available to look after it and there is no "failure pathway" option available.

## The consequences of increasing complexity

The consequences of unmanageable complexity are easier to see now that a decade of research has been carried out on user-related topics. The *Office Environment Survey* was the first large-sample study of occupant problems in office buildings in the United Kingdom [Reference 7]. Many of its early findings, most of which were initially posed as speculative hypotheses, have been subsequently corroborated by other studies [Reference 12, for instance]. Increasingly, emphasis has shifted away from physical design variables as being the main culprits for ill-health problems (except where they are manifestly faulty) towards management and maintenance issues [Reference 13]. Many of the most important associative factors had been identified in earlier studies. These included the likely effects of perceived control, comfort, productivity, as explained in the following paragraphs.

### Control

Building occupants often say that control over heating, cooling, ventilation, lighting and noise in offices is important to them. However, the actual levels of control that they perceive are often low or very low. Control is so obviously important for human comfort that it has even been suggested that the association between greater comfort and more control is almost trivial! [Reference 4] Control over cooling and heating seems to be more important than control over ventilation, lighting and noise [Reference 5].

Despite this, there has been a trend to remove manual environmental control from occupants and replace it with central, automatic systems. Many factors are relevant here. Offices have become deeper in the search for greater spatial efficiency, and floors have been more densely populated with people in open-plan layouts, so the need to air condition these spaces has increased. With increased depth comes a lower proportion of people with window seats. Whether or not people in window seats actually have more control does not matter very much, they perceive that they do and their satisfaction and comfort goes up accordingly (except in one or two buildings with extremely poor perimeter environments and control levels). The people in the middle perceive that they have less control and report lower satisfaction; they are often of lower status, sit at their desks for longer sustained periods in conditions which are objectively worse - noisier, hotter and dustier, for instance. Even the visible windows may turn into a nuisance because they have no direct control of them.

People who have control are also less critical of actual conditions, as in naturally-ventilated, "free-running" buildings. In air-conditioned buildings, lower levels of personal control seem to make people less tolerant, even though conditions may be objectively better. For example, failed air-conditioning makes people hypersensitive, perhaps because they do not know how bad things are going to get or because of the perceived total loss of control [Reference 6].

From the perspective of controls it is important that:

1. the building in operation keeps environmental variables within generally acceptable tolerance bands as much as possible;
2. it can be predicted with reasonable degrees of accuracy the degree to which perceived conditions are likely to move outside these thresholds, so that
3. designers can provide appropriate means for occupants to adjust the conditions effectively and quickly if and when they want to change them; and
4. workable management systems are provided which give occupants and managers the opportunity to adjust settings in advance of need should they need to do so, rather than simply in response to it.

In Britain, the best office buildings, measured by occupants' perceived comfort and the buildings' energy efficiency [Reference 5], normally work well in all four of these control categories. The tendency in office design, though, has been to concentrate only on the first of the four, with "close controlled", air-conditioned buildings being expected to provide good personal comfort through automatic systems without either individual control or simple, effective means of management intervention. Occupants need to perceive that they can change the conditions, if they so wish, and that change in the right direction happens quickly.

### Comfort

Are air-conditioned buildings more comfortable than naturally-ventilated? Surveys in Britain have shown in Britain that the mean occupant satisfaction may well be about the same for both [Reference 7]. Buildings vary, of course, and some are much better than others. For example, in occupant surveys carried out by Building Use Studies in 1992/1993, both the least and most comfortable buildings in detailed studies of 11 office buildings were air-conditioned [Reference 8].

As a general rule, owner-occupied buildings perform better in comfort and energy terms than multi-tenanted ones. However in Building Use Studies' recent surveys, "pre-lets" - buildings which were let in advance of construction by a developer for occupancy by a known tenant - did best. Where a strong tenant had some influence on the design and thereby "owned" some of the problems, significant performance improvements were observed. This is suggests that "comfort" is at its highest not simply where the design criteria are met but also where appropriate building procurement and management systems are in place. Comfort can be measured in the laboratory and predicted with equations, but it ultimately depends on the given context.

### Health

In the 1980s and 1990s, much effort has been put into discovering why certain office buildings seem to create chronic ill-health in occupants. The answers for this often come in the form in which the problem is stated: ventilation engineers see it as an air quality problem requiring better ventilation, ergonomists as a property of lighting and workstation design, physicians view it as the increased propensity of the building to harbour pathogens and reduce the performance of the immune system, and social psychologists regard building-induced stressors as more important in lowering individuals' tolerances, for example.

There is little doubt that certain types of buildings are linked with chronic ill-health and that the risk of ill-health is higher in air-conditioned, deep-plan plan offices with higher proportions of sedentary, clerical staff [Reference 7]. However, the root cause should not be seen as the air-conditioning by itself. Such buildings may also be both complex and relatively poorly managed (in terms of the ability of the management to cope with the demands that the building's complexity places upon them), leading to operating, cleaning and maintenance failures which, in turn create the physical and attitudinal conditions under which chronic illnesses are more likely to develop. Poor management is also more likely to bring about work-related stress problems. Once created, these attitudes may predispose people to think that their building is poor, or to project onto the building problems which should properly be dealt with by management in other ways. In many cases, it is difficult or impossible to disentangle causes and effects.

Ultimately, many health problems go back to a lack of cleanliness, which in turn will be related to lack of resources or lack of management effectiveness or diligence. If a building is costly and difficult to manage because it is too complex then this may be the root of the problem. Thus a ventilation system which is simple to maintain and clean will ultimately tend to be the most effective as it is more likely to be kept clean and well-maintained, either routinely or at least once a crisis develops.

Air-conditioned buildings are intrinsically more complex, often deeper in plan form and many of their occupants have less control and views out (lack of outside awareness is often complained about in offices). If this complexity proves unmanageable and leads to insufficient maintenance or cleaning, for example, then the likelihood of chronic ill-health amongst the occupants increases.

Ill-health will, in turn, lead to further problems with the occupants which will make the situation worse. Naturally-ventilated buildings tend to be better from the health point of view because they are usually simpler in technology, shallower in plan form, can have higher air-change rates when required (thereby helping to dilute airborne pollution), offer occupants more control (usually through opening windows but also radiator valves and local light switches) and are easier to maintain. They are not necessarily cleaner though, nor is their air quality necessarily better! Nor would many air-conditioned buildings be directly convertible to natural ventilation, owing to location, spatial arrangement, internal heat gains and so on.

Productivity

Productivity is extremely difficult to measure in an office environment. Some routine tasks, like data entry or time taken on the telephone, can be monitored, but many managerial tasks have no obvious objective measure. Several authors have shown a link between productivity and occupants' actual or perceived control over their environment. [References 7 and 9]: the less the perceived control, the more likely occupants will say that their productivity is reduced by the office environment. As perceived control is also linked to satisfaction and low incidence of chronic illness, it is reasonable to surmise that control, comfort, satisfaction and productivity are all positively associated.

Office environments with high perceived control are more likely to be more productive for their occupants. But high perceived control and high actual control is not necessarily the same thing. In the "best" air-conditioned buildings in reference

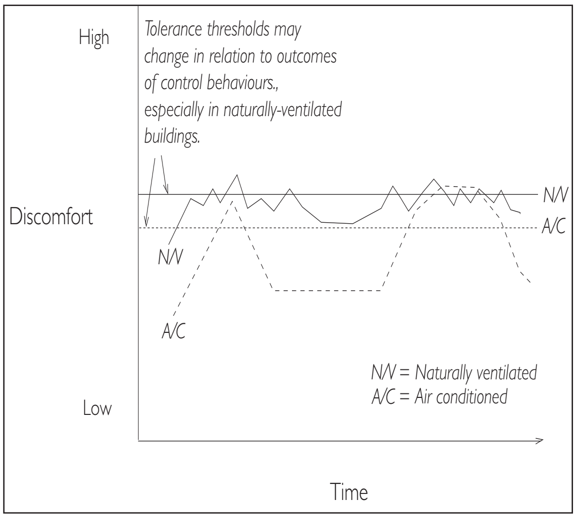



**Figure 3 (top)**
**Occupants' tolerance thresholds**
This represents likely differences in performance between naturally-ventilated and air-conditioned offices with respect to users' tolerance of the conditions and the ability of the building to respond when people become uncomfortable. Naturally-ventilated (sometimes called "free-running") offices have higher user tolerance (because they usually offer more user control) and more rapid response, but the control systems only tend to alter conditions marginally. Air-conditioned ("close control") buildings have lower user tolerance and slower responses, and often run for longer periods of time either inside or outside the comfort zone, with the control systems having larger effects on conditions. For some people. local conditions may be outside the comfort zone for long periods as local adjustments, for example, to air distribution, are not readily possible.

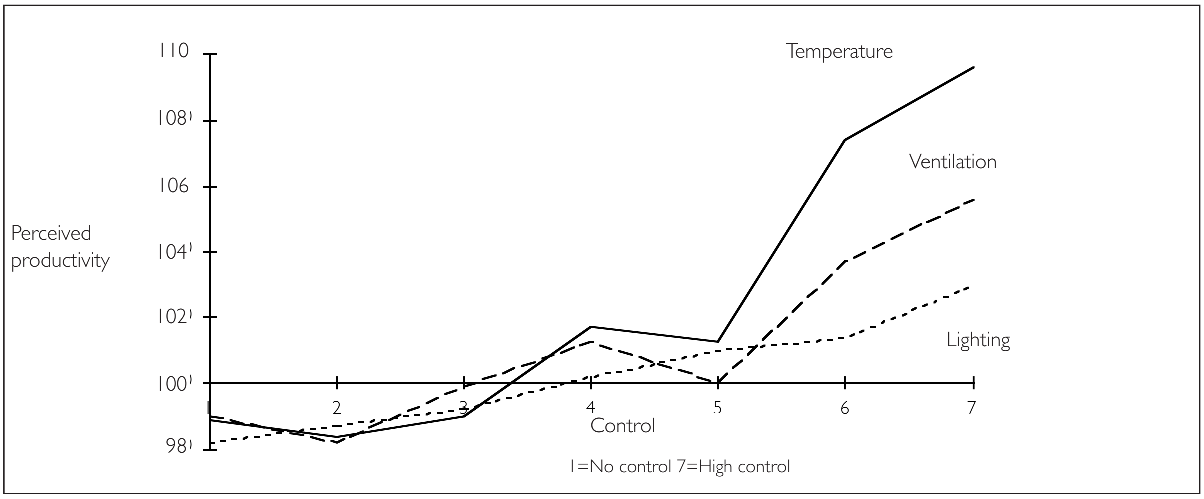



**Figure 4 (above)**
**Perceived productivity and perceived control over temperature, ventilation and lighting**

Note that people report levels of control over 5 on the scale onl infrequently.

Source: Gary RAW, Michael ROYS, and , Adrian LEAMAN, *Further Findings from the Office Environment Survey: Productivity* Proceedings of the 5th International Conference on Indoor Air Quality and Climate, Toronto, Canada, 1, 231-236 Ottawa: Canada Mortgage and Housing Corporation, 1990.

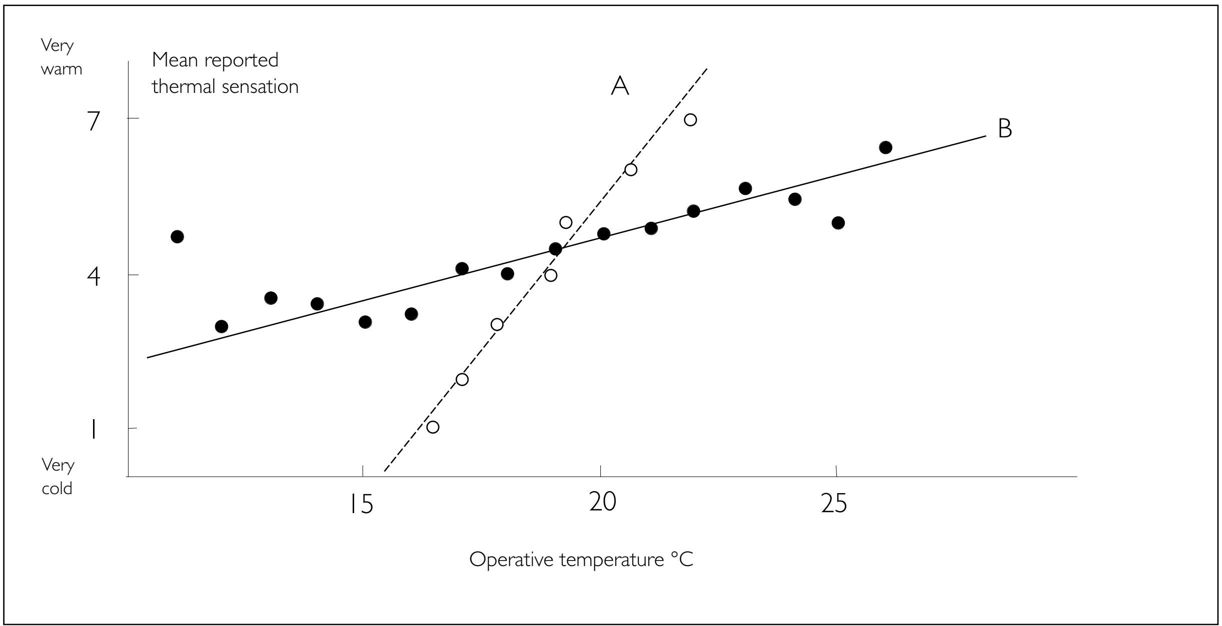
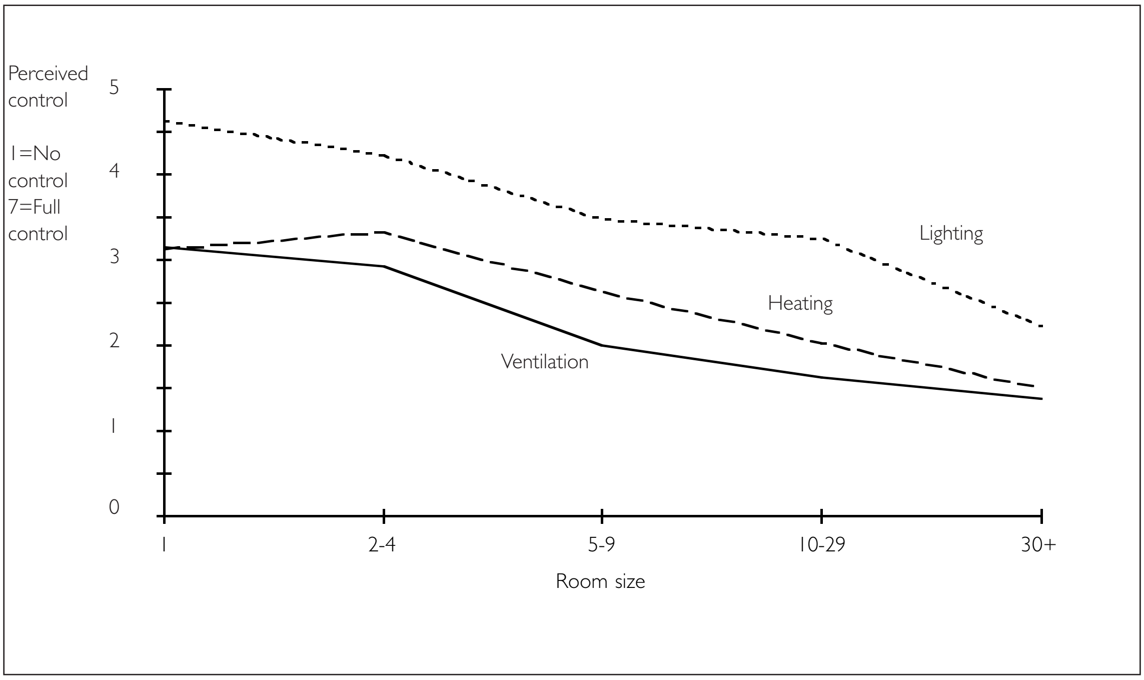



**Figure 5 (above)**
**The relationship between temperature and thermal comfort under constrained (A) and unconstrained conditions (B).**

When people have more control (B), they tolerate temperatures over a wider range. These data are for wintertime conditions.

Source:: Nigel OSELAND, Reference 10

**Figure 6 (below)**
**Perceived control and room size**
As rooms get bigger, perceptions of control decrease, with the effect most apparent for lighting.
Source: Building Use Studies



| Control over … | Buildings n=58<br>n-1476 | Buildings with samples of more than 20 staff = 24 |
|---|---|---|
| | Individuals | Buildings |
| | Spearman's Rho corrected for ties | Spearman's Rho corrected for ties |
| Heating | -0.24<br>p=0.0001 | -0.62<br>p=0.0031 |
| Cooling | -0.15<br>p=0.0001 | -0.67<br>p=0.0014 |
| Ventilation | -0.19<br>p=0.0001 | -0.47<br>p=0.0244 |
| Lighting | -0.15<br>p=0.0001 | 0.017<br>p=0.1871 Not significant |
| Noise | -0.21<br>p=0.0001 | 0.1871<br>p=0.1142 Not significant |

Perceived control is measured on a scale from 1 (no control) to 7 (high control), with a scale mid-point of 4.

Perceived productivity is measured on a scale from 1 (increase of 40% or more) to 9 (decrease of 40 per cent or more), with a scale mid-point of 5.

**Figure 7: Perceived control and productivity**
These data are from a 1993 survey by Building Use Studies of 58 office buildings in Britain belonging to a single organisation. The table show correlations (Spearman's rho corrected for ties) between perceived control and perceived productivity first for all individuals in the sample (n=1476), then for those buildings which had samples of greater than 20 respondents (number of valid buildings = 24).

Correlations are lower on an individual basis, but significant. For buildings as a whole, correlations are higher but not significant for lighting and ventilation.
Conclusion? Perceived control over heating, cooling and ventilation are vital for productivity gains, but these are the very elements which are most difficult to provide, especially control over cooling.

8, the actual level of control was quite low but occupants perceived control as good because the systems worked quite well and the management responded immediately to any complaints Designers now talk about giving people more individual control but this may not have the effect intended, especially if conflicts between control functions are unwittingly introduced or controls are included gratuitously or the consequent system increases complexity and proves difficult to maintain and manage.

## Relationships in the data

### Control and Productivity

Figure 4 shows how perceived comfort and perceived productivity are related. Control over temperature yields the best productivity gains; control over ventilation is next in importance, then control over lighting [Reference 7], normally the same order of difficulty of providing these services. This implies that designers should pay particular attention to supplying control over heating and cooling. Figures 7 and 8 show more detailed statistics for a different data set for perceived control and productivity for both individuals and buildings (Figure 7) then perceived control and comfort (Figure 8). The building correlations are higher than individuals for the same variables, so building design is having a measurable effect.

### Comfort and Control

Figure 5 shows how perceptions of thermal comfort change under constrained and unconstrained conditions [Reference 10]. The temperature curve predicted by thermal comfort theory is much steeper (that is, there is much less tolerance) than when occupants are allowed to set their own temperatures. This matches experience of differences in user tolerance between close control (air conditioned) and free-running (naturally ventilated) buildings shown in Figure 3.

### Control and Depth

Figure 6 show how perceptions of control decrease as buildings get deeper. This pattern is repeated in many buildings. Control tends to be subjectively lower where conditions are also worse, which is often in the middle of the space. This applies whether or not the occupants objectively have less control. Similarly, there are strong associations between perceived comfort and whether or not occupants have window seats. Needless to say, window seats are much better.

### Productivity and Ill-Health

Figure 9 shows the relationship between perceived

| Control over … | Buildings n=58 n-1476<br>Individuals<br>Spearman's Rho corrected for ties | Buildings with samples of more than 20 staff = 24<br>Buildings<br>Spearman's Rho corrected for ties |
|---|---|---|
| Heating | 0.31<br>p=0.0001 | 0.69<br>p=0.0010 |
| Cooling | 0.23<br>p=0.0001 | 0.74<br>p=0.0004 |
| Ventilation | 0.22<br>p=0.0001 | 0.53<br>p=0.0110 |
| Lighting | 0.25<br>p=0.0001 | 0.46<br>p=0.274 |
| Noise | 0.25<br>p=0.0001 | 0.56<br>p=0.0077 |

Perceived control is measured on a scale from 1 (no control) to 7 (high control), with a scale mid-point of 4.

Overall comfort is measured on a scale from 1 (low) to 7 (high)

**Figure 8 Perceived control and overall comfort**

These data are from the same 1993 survey as Figure 7. The table show correlations (Spearman's rho corrected for ties) between perceived comfort and perceived productivity first for all individuals in the sample (n=1476), then for those buildings which had samples of greater than 20 respondents (number of valid buildings = 24).

Correlations are all significant for individuals and buildings, with individual correlations lower than those for buildings
Conclusion? Perceived comfort is significantly related to perceived productivity.

productivity and ill-health symptoms. Mean scores for perceived symptoms are on the bottom axis, and perceived productivity on the vertical axis.

### Energy efficiency

The relationships between control, productivity, health and comfort described above are, to some extent, self-evident. Less so the connection between control, comfort and energy efficiency. Figure 10 [Reference 5], shows how both perceptions of comfort and control are directly related to energy efficiency - the higher the comfort, the lower the energy consumption. As with many effects in buildings, intervening variables actually make the link. In this instance, management and the "culture" of the occupiers plays an important part. A motivated facilities manager, backed by a clearly-targeted corporate mission, often produces buildings which are more "demand-led", that is, more closely tailored to everyday needs and long-term requirements, and also efficient and economical.

### Strategy

Buildings increase human potential by reducing variation in the natural environment. The conditions they create indoors allow more activities to be carried out for longer periods of time than they might otherwise. Creating comfortable, healthy conditions which allow human potential to develop in as unconstrained a way as possible is what buildings are for. They must also be relatively economical and not consume more resources over their lifetime overall than they help to create. As soon as wealth and potential-creating activities are threatened by discomfort, ill-health, excessive cost or resource depletion then buildings lose value and may become obsolete.

### Constraints and opportunities

Designers and managers usually have the same overall strategy. They try to minimise the actual or predicted effects of constraints in order to maximise opportunities. But they do it from different standpoints. Designers have to operate within predominantly prescriptive (often legal and budgetary) constraints in order to provide usable space for the often unforeseeable requirements of management and users. User/managers, on the other hand, have to work within buildings which have already been prescribed or fixed for them. and also within

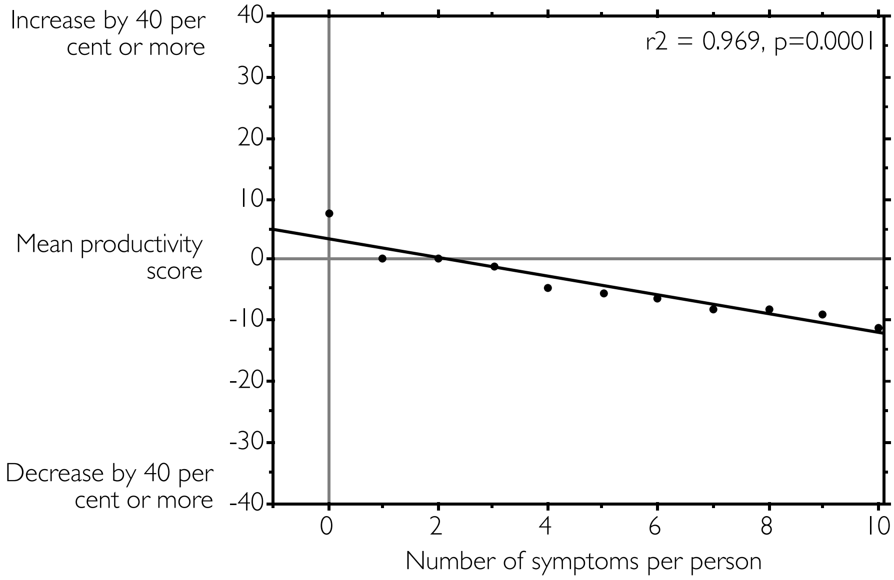



**Figure 9**
Perceived productivity and ill-health symptoms
Symptoms are based on self-reports of chronic ill-health symptoms. Productivity is self-assessed by questionnaire on a 9-point scale. An average of 2 or more symptoms is a likely indicator of overall productivity losses.

Source:
Building Use Studies and Reference 7

changeable conditions created by the fluctuating needs of their organisation, the external environment and the marketplace.

The designer has to “second guess” management and user behaviour, often by stereotyping or over-simplifying it. Designers can often make unrealistic assumptions about management availability and occupants’ capacity to know, to do and to communicate. This makes the design task easier but can introduce complications later for management. Managers, on the other hand, are constantly entreating designers to deliver “flexibility” so that they they may optimise their responses in an uncertain organisational environment, thereby making the management task easier. “Flexibility” is the managers’ codeword for “maximise opportunities, minimise constraints”. In responding to this, designers can easily maximise uncertainty and make the solution require too much management attention.

In many instances, well-intentioned actions ultimately turn out to have unintended consequences, which are often difficult to predict in advance and even more difficult to reverse when they occur. Many of these consequences are externality costs, which are also at the heart of modern environmental problems: they include other peoples’ noise, pollution and waste, for instance, and occur indoors as much as outdoors. Good design seemingly creates opportunities out of apparent constraints, while avoiding externality effects as much as possible. Bad design seems to deny opportunities by remorselessly uncovering new constraints, and creating more nuisance than it removes.

### Increased constraints

Because of the hierarchic properties of buildings and their sub-systems, designers should aim to pass on as few constraints as possible to the levels beneath (see Figure 1). Otherwise, options and opportunities are progressively removed from the functions lower down. More and more prescriptive constraints are being added, primarily through legislation, but also through increasingly stringent client requirements. This not only makes designers’ tasks harder, but can also make it difficult for managers and users to have sufficient degrees of freedom at lower levels to operate effectively within their preferred envelopes. Although the number of possible theoretical design solu-

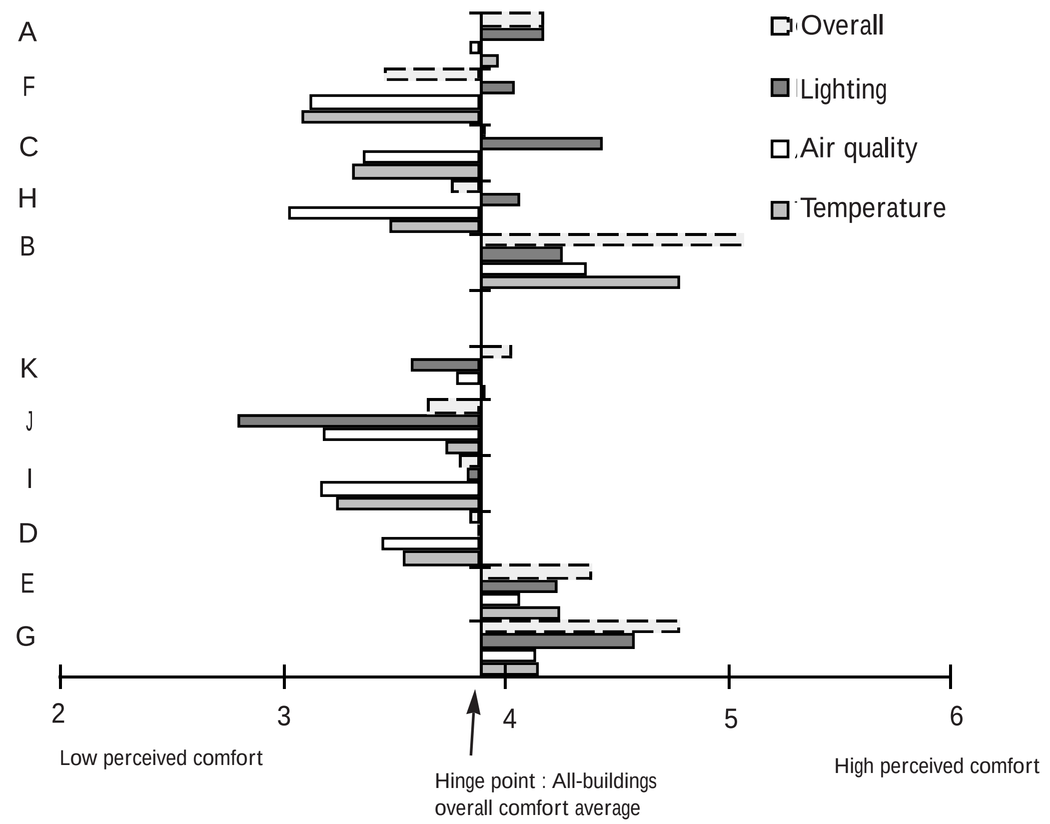



**Figure 10**
**Perceived comfort and energy efficiency**
Buildings A,F,C,H and B are air-conditioned; K,J,I,D and E naturally-ventilated.
For each group, buildings are ranked by energy efficiency (best at bottom).
The scale is a 7-point satisfaction scale (1=low, 7=high). Individual building occupants are surveyed by questionnaire. The scores are hinged at 3.8 (a 50-building average for overall comfort from reference 1).

Source: Reference 5

tions is getting bigger because of advances in materials and technology, the number of potentially successful solutions could well be decreasing owing to the multiplicity of increasingly conflicting constraints.

Not only are prescriptive constraints increasing, but there is greater turbulence, instability and uncertainty in the constraints with which managers must deal. Designers thus look to managers for help: “Define the brief more clearly!”; managers look to designers and consultants: ”We want flexibility!”; and users look to managers “We want control!” ”We want window seats!”.

It is now unrealistic to think that most types of non-domestic buildings can properly satisfy all the required theoretical constraints. Outcomes are not just sub-optimal with respect to all criteria, but often meet only a sub-set of criteria. This is happening already in offices, where increasingly exacting requirements for non-conflicting individual control, avoidance of glare, cooling, fresh air, ventilation, lighting and noise control cannot be met in all circumstances. Occupants are then forced to discount disbenefits - sacrificing fresh air for glare avoidance or tolerating over-hot conditions in order not to give up their view out, for example. When designers are called in to help solve discomfort problems, they may relieve one set of complaints by exchanging them for another. For example, they may increase humidity to relieve complaints of dryness, only to find that another group of people complains that it is too stuffy or they relieve solar gains and glare and get complaints about loss of daylight and views out.

In some circumstances, consultants who are hired to increase management options may unwittingly reduce them further because they fail to appreciate how constraint-bound buildings are in their functions. Space planners, for instance, may re-plan an office floor on the basis of furniture configuration and layout alone, without considering how the new arrangements affect access, control and servicing for heating, ventilation and lighting. This can be an expensive way of increasing occupant discomfort and energy costs!

Furniture planners often find that constraints such as grid dimensions, floor depths, circulation routes, cabling and location of services restrict their options. The resulting layouts then, in turn, affect individual users' capacities to fine-tune their workstations to their own requirements in response to changing conditions. They may wish to change the orientation of their computer screen as the sun moves round the sky to avoid glare, for instance, but may be prevented from doing so by a combination of the fixed workstation and the VDU itself. There are countless similar examples, many of which seem too trivial or anecdotal to be worth bothering about, but which in total add up to a significant failure of design to meet need.

## Summary

This paper has reviewed recent evidence about people and their performance in office buildings and presented it in a wider strategic framework, with emphasis on understanding the part that complexity plays in building design and management.

Two types of complexity have been identified. The first is concerned with increasing chance of functional conflict, which is primarily related to the physical performance of the building, its spaces and activities. The second arises from the requirement for people to carry out tasks without hindrance of uncertainty, where they need predictable, responsive outcomes when there is a need for them to make interventions or changes.

Commonly, one type of complexity is mistaken for the other and, when this happens, strategies can be introduced which may produce the opposite effects to those intended. This often occurs with the introduction of open-plan offices, for instance.

In order to cope with this complexity, which is growing inexorably in modern buildings, offices must become more demand-responsive. Wherever effort has been made to respond more rapidly to managers' and users' needs and requirements - through better briefing, cleaning, maintenance and commissioning, for example - tangible benefits have resulted. These can now be seen in evidence emerging from studies of comfort, productivity, health and energy efficiency.

Achieving this, though, involves a radical change in perspective by designers and managers from thinking which is dominated by industry supply criteria to much greater sensitivity to user demand criteria. More attention must be given to the building brief and design objectives, and to assessing whether or not these have been met. Managers must make greater efforts to convert their organisations' mission into coherent programmes for design, so that there is a consistent overlap between everyday management practices and design outcomes. Many people pay lip-service to "user needs" (almost a byword for ignoring them!), but rarely monitor complaints and act on them promptly (managers are often fearful of being shown up to be incompetent). Many still only cursorily acknowledge environmental requirements without realising that bonuses for the environment can also be bonuses on organisational performance and bottom line profit.

Most of all, offices must be more manageable to meet the complexity challenge, because lack of manageability is the greatest cost to the occupiers in lost productivity, comfort and reduced health. The search for management efficiency and quality will force people to think more about strategic options earlier in the design process, and, in so doing, place much greater emphasis on design for manageability.

## References

1 Herbert SIMON, *The Sciences of the Artificial, Second Edition, MIT Press,1981, p 43.*

*2* Energy Efficiency Office, *Energy Consumption Guide 19*, Best Practice Programme, BRECSU, Building Research Establishment, Oct 1991.

3 Adrian LEAMAN, *Rapid Response*, Facilities, Vol 11, number 2, Feb 1993.

4 David WYON, Panel comment at *BRE Thermal Comfort: Past, Present and Future* conference, Building Research Establishment, 9-10 June 1993.

5 Bill BORDASS and Adrian LEAMAN, *Control Strategies for Building Services*, Advanced Systems of Passive and Active Climatisation, Barcelona, Institut Catala d'Energia (ICAEN), June 3, 1993.

6 R. de DEAR, Presentation to *BRE Thermal Comfort: Past, Present and Future* conference, Building Research Establishment, 9-10 June 1993.

7 Sheena WILSON and Alan HEDGE., *The Office Environment Survey*. Building Use Studies. London, 1987.

8 Ken BROMLEY, Bill BORDASS and Adrian LEAMAN, *Improved Utilisation of Building Management and Control Systems*, BRE PD 10/93 and CIB/IEA Symposium on Energy Efficient Buildings, Stuttgart March 1993. (Version available from authors)
Bill BORDASS, Adrian LEAMAN and Steve WILLIS, *Control strategies for building services: the role of the user*, Buildings and the Environment, BRE, 16-20 May, 1994.

9 David WYON, *Indoor Air Quality, Productivity and Occupant Control*, Indoor Air Bulletin, 1(7), 1991,1-6.

10 Nigel OSELAND, Presentation to *BRE Thermal Comfort: Past, Present and Future* conference, Building Research Establishment, 9-10 June 1993.

11 Adrian LEAMAN and Iain BORDEN, *The Responsible Workplace: User Expectations*, Chapter 2 of DUFFY F., LAING A, and CRISP V., *The Responsible Workplace: the redesign of work and offices*, Butterworth Architecture, London, 1993.

12 PJ JONES (and six other authors), *Health in the Workplace: a review of a contemporary investigation*, Second Indoor Air Quality conference, Mid-Career College, 22 June 1994.

13 Adrian LEAMAN, and David TONG, *The Indoor Environment: Strategies and Tactics for Managers*, Chapter 5 of Alan SPEDDING (ed) The Chartered Institute of Building (CIOB) Facilities Management Handbook, 1994, forthcoming, Times Newspapers/CIOB.



Adrian Leaman 90 Bootham York YO3 7DG UK
Telephone +44 (0)904 671280 Fax +44 (0)904 611338 EMail AL18@YORK.AC.UK

Dr Bill Bordass 10 Princess Road London NW1 8JJ UK
Telephone and Fax +44 (0)71 722 2630